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Electrical and Chemical Interactions at Mars Workshop

Part I—Final Report

*Proceedings summary of a workshop
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PREFACE

The Electrical and Chemical Interactions at Mars Workshop, hosted by NASA Lewis Research Center on November 19 and 20, 1991, was held with the following objectives in mind: (1) to identify issues related to electrical and chemical interactions between systems and their local environments at Mars, and (2) to recommend means of addressing those issues, including the dispatch of robotic spacecraft to Mars to acquire necessary information. The workshop began with presentations about Mars' surface and orbital environments, Space Exploration Initiative (SEI) systems, environmental interactions, modeling and analysis, and plans for exploration. Participants were then divided into two working groups: one to examine the surface of Mars; and the other, the orbit of Mars. The working groups were to identify issues relating to environmental interactions; to state for each issue what is known and what new knowledge is needed; and to recommend ways to fulfill the need. Issues were prioritized within each working group using the relative severity of effects as a criterion. This report describes the two working groups' contributions. When materials were available in viewgraph form, the presentations given at the outset of the workshop are included as an appendix in Part II, published as a separate document. A bibliography of materials used during the workshop and suggested reference materials is included.

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INTRODUCTORY INFORMATION

DEFINITION: SPACE SYSTEM/ENVIRONMENT INTERACTIONS

Space system environment interactions comprise a set of phenomena which occur when a system is placed into an environment whose local characteristics are such that the system and the environment are able to communicate in some way and thereby modify each other.

ENVIRONMENTAL INTERACTIONS WORKING GROUP

The Environmental Interactions Working Group, chaired by J. Kolecki and G. Hillard of NASA Lewis Research Center, is part of the Engineering Requirements Subgroup (ERS) which aids the Robotic Mission Working Group (RMWG) in developing robotic mission program requirements for the Space Exploration Initiative (SEI). Other working groups in the ERS include Engineering Test and Demonstration, Lunar Surface Knowledge Requirements, Mars Surface Knowledge Requirements, Mars Atmosphere Knowledge Requirements, Human Support, and Navigation Requirements.

The objective of the Environmental Interactions Working Group is to identify environmental interactions issues, and formulate and document robotic precursor mission requirements based on these issues. This workshop was the first of several conceived to address issues of environmental interactions for SEI. It brought together experts from around the country, representing a variety of disciplines. Its specific focus was the planet Mars and the electrical and chemical interactions which are to be expected when exploration systems are orbited or landed there. In addition to electrical and chemical interactions, a set of mechanical interactions was also identified during the course of the two day meeting, and are included in this writeup as part of the workshop results.

Executive Summary:

SYNOPSIS OF WORKSHOP CONCLUSIONS/RECOMMENDATIONS

I.) SURFACE

1.) No hard knowledge exists of the Martian subsurface, and while structures in Martian bases must interact with the subsurface, no missions are currently being planned to explore into this realm. The following information about the subsurface is required:

- i.) The presence or lack of subsurface water and its state (liquid or solid, fresh or brine)
- ii.) Subsurface soil mechanics and mineralogy
- iii.) Mechanical, thermal, electrical, and chemical properties of subsurface rocks and soil
- iv.) The nature and distribution of volatiles and their chemical properties.

Therefore, surface rovers should include instrumented probes to characterize the subsurface whenever and wherever such inclusion is feasible.

2.) On the martian surface, dust plays a major role in just about all of the surface interactions considered. The following information on Martian surface dust is required:

- i.) Surface soil mechanics and mineralogy
- ii.) Mechanical, thermal, electrical, and chemical properties of surface rocks and soil
- iii.) The explosion potential of suspended dust in confined volumes
- iv.) The nature and distribution of volatiles and their chemical properties.

Therefore, robotic missions (whether surface rovers/landers for in situ observations or orbital for remote global reconnaissance) are recommended to characterize the surface.

3.) The Martian atmosphere also is reactive, and capable of sustaining Paschen type electrical breakdowns. At a minimum, such breakdowns are a source of EM noise to instruments operating on the Martian surface. The following about the Martian atmosphere information is required:

- i.) The thermal and electrical breakdown characteristics of the Martian atmosphere in the presence and absence of dust, with and without wind, and the magnitude and direction of the ambient electric field.

Therefore, surface robotic missions must include appropriate instrument and experimental packages to characterize the martian atmosphere.

4.) The surface radiation environment will impact all aspects of a Mars mission, human and

systems related. Knowledge of Mars specific environments is lacking. The following information about the surface radiation environment is required:

- i.) Solar flare and galactic cosmic ray radiation spectra
- ii.) Models to estimate levels of induced radiation
- iii.) Surface mapping of induced radiation levels.

Therefore, surface robotic missions must include appropriate instrument and experimental packages to achieve these objectives whenever it is feasible for them to do so.

While the planned Mars Observer, MESUR, MAO, and Mars 94/96 missions will provide much needed data on conditions at the planet, it was agreed that additional information must be sought on:

- i.) Surface conditions such as composition and distribution of native materials
- ii.) Dust processes associated with disruption and reformation of the duricrust
- iii.) Chemical activity, nature and distribution of volatiles
- iv.) Chemical composition and breakdown characteristics of the atmosphere in its various states of rest and motion, dustiness and relative clarity
- v.) Reactivity of soil and atmosphere in the presence of heat and fluids
- vi.) Solar and galactic cosmic ray radiation spectra and induced surface radiation levels
- vii.) Abrasive properties, electrical properties (including electret and dipole formation), and melting/decomposition properties of dust
- viii.) Explosion characteristics of Martian dust suspended in closed volumes.

II.) ORBIT

The orbital working group defined issues in the spatial regime extending from 100 km altitude upwards. These issues include:

- i.) Atomic oxygen erosion of materials
- ii.) CO₂ damage to refractory metals
- iii.) CO chemical reactions
- iv.) Plasma interactions in the ionosphere
- v.) Erosion and charging due to a hot O⁺ tail (≤ 60 KeV) extending behind the planet
- vi.) Dust erosion
- vii.) Penetration by particulates like meteoroids and ejecta from the moons
- viii.) Man-made debris including particulates from propellants
- ix.) Radiation (optical and ionizing) and solar UV damage to materials
- x.) Aerocapture related effects including those due to locally generated plasma and dust erosion, and effects of such atmospheric anomalies as gravity waves
- xi.) Transport of surface dust into orbit by ascent vehicles
- xii.) System generated environments and their effects

These twelve issues break into four broad groups:

- i.) Electrical interactions with plasmas and neutrals which include spacecraft charging, spacecraft potential variations, structural currents, and erosion due to local sputtering
- ii.) Interactions with particulates (solid materials like meteoroids and debris) in low Mars orbit (LMO) which include mechanical erosion or penetration of spacecraft surfaces
- iii.) Chemical interactions which include erosion by atomic oxygen and/or species liberated from local CO and CO₂, and photochemical reactions on surfaces and degradation within materials due to the presence of solar UV
- iv.) Radiation interactions including the effects of cosmic ray and solar flare particles on humans and on system components.

Recommendations were made for robotic precursor missions to:

- i.) Comprehensively map the atmosphere in LMO, including the spatial and temporal characteristics which affect orbital mechanics, and ascent/descent maneuvers (including g-wave characteristics and drag uncertainties), diurnal and solar cycle variations in the temperatures and densities of atomic oxygen, the hot O⁺ tail, CO, and CO₂ populations
- ii.) Determine the effects of high energy impacts with all of these species upon spacecraft structures and materials
- iii.) Evaluate and define the Mars specific radiation environment including solar wind, solar flare, and galactic cosmic ray components
- iv.) Measure suspended dust populations and size distributions over time
- v.) Understand impact cloud characteristics corresponding to aerocapture altitudes, velocities and densities
- vi.) Evaluate system generated effects such as those due to the addition of effluents or solid debris.

It was proposed that several of these test and measurement functions might be combined in one spacecraft or platform like the Aeronomy Observer with time varying orbital parameters and sufficiently diverse instrumentation. Additionally, it was recommended that ground tests and model development either be continued or begun. Specific areas of opportunity include:

- i.) Subsystem laboratory tests and analytic modeling of spacecraft plasma interactions in a martian cold plasma environment
- ii.) Laboratory measurements of sputtering and erosion interactions at 60 KeV energies.

These activities must keep pace with SEI program development and ensure timely availability of design tools for SEI system engineers.

WORKSHOP REPORT

SOME "STRAW MAN" ENVIRONMENTAL INTERACTIONS CONCERNS/QUESTIONS

These strawman concerns/questions were presented to the working group at the outset of the meeting to catalyze the formation of ideas. They originated in numerous discussions and meetings relating to Mars and the SEI over a period of several months.

1.) *PASCHEN ELECTRICAL BREAKDOWN IN THE LOW PRESSURE MARTIAN ATMOSPHERE*

The Paschen curve for carbon dioxide shows a minimum at the 7-9 torr Martian surface pressure, which means that Paschen electrical breakdown will occur readily on Mars. At this pressure, millimeter to centimeter long discharges are possible at voltages up to a few hundred volts, and centimeter to meter discharges from a few hundred to a few thousand volts. What role does Paschen breakdown play in production of E.M. noise, electrical power loss, astronaut safety? Will Paschen breakdown be a "major concern" or a "minor annoyance" to unmanned robotic systems? larger manned systems? powered permanent habitations? multikilowatt surface power systems? What can be done to deal with Paschen breakdown in systems designs?

2.) *CHARGED OR POLARIZED SAND AND DUST*

Electrical forces may play a role in Martian dust physics, specifically in the formation of soil agglomerates and possibly dunes. Also, electrical power system grounding is difficult on Mars because of extremely dry conditions. What role does electrically charged dust play in contamination? Astronaut safety? Do Martian soil grains form electric and/or magnetic dipole structures? What role do these structures play? Will triboelectric ("frictional") dust charging occur during dust storms? Will differential dust settling after dust storms result in electrical fields and set up conditions for Mars "lightning?" Will vehicles on excursion across the Martian soil become electrically charged? What can/should be done to deal with charged dust in systems designs?

3.) *ELECTRICAL DISCHARGES ACCOMPANYING ASCENT/DESCENT ENGINE FIRING*

Observation of electrical discharges associated with launch operations on Earth coupled with the surface characteristics of Mars (high probability of Paschen breakdown, charged dust, etc.) make this scenario a possibility for Mars. What mechanisms might be involved? How great a problem is posed? Should provisions be made to eliminate discharges during engine firings?

4.) *ATOMIC OXYGEN and CO₂ IN LOW MARS ORBIT (LMO)*

Mars has an atomic oxygen and carbon dioxide environment comparable in density to that found in LEO. The LEO atomic oxygen is known to pose an erosion hazard to objects placed in long term orbit. Should similar hazards be assumed for objects placed in long term LMO?

5.) *MARS PLASMA ENVIRONMENT*

Mars has an ionosphere roughly an order of magnitude lower in density than LEO. The LEO plasma interacts electrically with all objects placed into it and must be taken into careful consideration in spacecraft design. Should similar interactions be assumed to occur in LMO? Are existing LEO models appropriate to use?

6.) *DUST, METEOROIDS, AND DEBRIS ENVIRONMENT*

Although dust, meteoroids, and debris may not be a major problem now, human presence in LMO may quickly alter this condition. Will landings on the Martian moons contribute to the orbiting dust environment? What reentry rates should be assumed for orbiting dust, meteoroids, and debris? How do Martian atmospheric parameters (such as scale height) vary with the martian year? What role does this variation play in the maintenance of an orbital dust, meteoroid, and debris environment?

7.) *RADIATION AT THE MARTIAN SURFACE AND IN LMO*

Mars does not have a significant magnetic field to trap particle radiation and/or shield astronauts from energetic particle fluxes from the sun and from space. What radiation hazards exist in LMO and at the surface? How should these hazards be addressed?

8.) *PLASMA GENERATION DURING AEROBRAKING*

Aerocapture has been considered for use at Mars. The atmosphere around the aeroshell will be heated and excited to form a thermal plasma. What issues surround this plasma? Do such phenomena as communications blackout during the aerobraking maneuver pose a problem to spacecraft? What issues (charging, electrical currents, etc.) are associated with plasma moving around the aeroshell and/or streaming back past the spacecraft? How should designers take these issues into account?

SUMMARY OF WORKSHOP RESULTS

INTRODUCTION

The workshop began with a series of presentations on Mars surface and orbital environments, SEI systems, environmental interactions, modeling and analysis, and plans for future exploration.

**STRAWMAN QUESTIONS/CONCERNS
CONDITIONS AT THE MARTIAN SURFACE**

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THE MARTIAN ATMOSPHERE

Robert Haberly, NASA/Ames

THE MARTIAN IONOSPHERE

Lawrence Brace, U. of Mich.

SEI/SYNTHESIS REPORT SYSTEMS SUMMARY

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SUMMARY OF ENVIRONMENTAL INTERACTIONS

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MODELING AND ANALYSIS TOOLS

Gary Jongeward, S-Cubed Div. of Maxwell Labs, Inc.

NASA MARS EXPLORATION: CODE SL

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Participants were then divided into two working groups:

THE MARTIAN SURFACE

CHAIR: Dr. Ira Katz, S-Cubed
Div. of Maxwell Labs, Inc.

MARS ORBIT

CHAIR: Dr. Carolyn Purvis, NASA
Lewis Research Center

The working groups were asked to identify issues in the form of environmental interactions, to state what is known for each issue, what new knowledge is needed, and to recommend ways of filling the need. Issues were to be prioritized within each working group using relative severity of effects as a criteria. The sections that follow outline upcoming missions, since these missions form a vital part of filling our knowledge needs at Mars. Systems are then outlined in broad, general terms. Environments are next described, subdivided into subsurface, surface, and orbit environments. Interactions are subdivided into electrical, chemical, and mechanical. Finally, knowledge requirements are described along with recommendations for ground based and robotic precursor activities. Although the contributions of the two working groups are presented in parallel within the body of this report, they are delineated by group name wherever possible.

Where materials are available in viewgraph form, the presentations given at the outset of the workshop are included as an appendix in a separate document. A bibliography of documented materials used during the workshop along with additional references that have been suggested during the writing of this report is also attached.

I.) UPCOMING MISSIONS

This section derives from presentations made by Dr. Brace and Dr. Dickinson along with reference materials supplied by these individuals and included in the bibliography at the end.

The missions described in this section include Mars Observer, Mars Environmental Survey (MESUR), small rover and sample return missions, and missions as part of the evolutionary Mars exploration program. Additional missions, mentioned during the course of the workshop but not formally presented, are the Soviet Phobos, and Mars 94/96 missions. Missions such as Viking and Mariner are not explicitly described in this report because their contribution to our knowledge of Mars was already contained in the numerous discussions and presentations engaged in during the workshop and are so represented here. The bibliography does contain listings of Mars documents used or made available to workshop participants.

MARS OBSERVER (MO)

Mars Observer is a geoscience/climatology mapping mission to be placed in a low altitude polar orbit, 2 pm - 2 am sunsynchronous, with an altitude of 350 km. The total mission duration is 1 Martian year. MO is a derivative of Earth orbital spacecraft and includes the following instruments:

- 1.) γ -ray spectrometer
- 2.) Magnetometer
- 3.) Pressure modulator
- 4.) IR radiometer
- 5.) Radar altimeter
- 6.) Thermal emission spectrometer
- 7.) MO camera

MO will fulfill the following mission objectives:

- 1.) Globally define topography and gravity field
- 2.) Establish the nature of the magnetic field
- 3.) Explore the structure and aspects of the circulation of the atmosphere
- 4.) Determine the time and space distribution, abundance, sources, and sinks of volatile material and dust over a seasonal cycle
- 5.) Determine the global elemental and mineralogical character of the surface material

MARS ENVIRONMENTAL SURVEY (MESUR) -

The MESUR Mission consists of as many as 16 light-weight stations and a communication orbiter launched over time aboard five medium-lift (Delta class) expendable launch vehicles. These stations will form a network over the surface and will simultaneously gather data about the Martian atmosphere, geology, and surface conditions.

MESUR represents a simple, relatively low-cost way to collect data at a variety of different sites. Each MESUR probe will fly independently to Mars. The following scientific objectives have been established for the MESUR mission:

- 1.) Determine the internal structure of Mars
- 2.) Improve our knowledge of Martian weather, atmosphere, and surface conditions
- 3.) Determine the Martian elemental chemistry
- 4.) Determine the ice content of the surface soils
- 5.) Determine the fine-scale structure of the Martian surface from a variety of sites
- 6.) Determine the structure of the Martian atmosphere

EVOLUTIONARY MARS ROBOTIC EXPLORATION

The Solar System Exploration Division's Mars exploration program planning is concentrating on an evolutionary approach to Mars exploration which will be responsive to the changing fiscal climate. Currently, exploration elements include Mars aeronomy, rovers, and sample return missions.

The Mars Aeronomy Observer (MAO) science goals have been thoroughly studied by the Mars Aeronomy Science Working Team in 1986. MAO is not in the Office of Space Sciences and Applications Strategic Plan for FY 94-99. Currently, alternate ways of achieving Mars aeronomy measurements are being considered in the context of an evolutionary Mars exploration program. The Mars aeronomy science goals include:

- 1.) Global in situ measurements of LMO environments, including upper atmosphere, gravity waves, and energetic particles in altitudes of 110 - 350 km
- 2.) Global imaging of the middle atmosphere in the UV and visible bands
- 3.) Global remote sensing of atmospheric density and dust at all local times.

The return of Martian samples to Earth laboratories has the highest science priority for an understanding of Mars as a planet, and as a place to visit with robots and humans. Different regions yield different types of rocks and soils and enable understanding of different aspects of the complex, highly diversified Martian geology. To suggest some examples:

- 1.) Heavily cratered material gives information about early geologic history
- 2.) Volcanic rocks yield information on planetary age and composition
- 3.) Sedimentary rocks gave information about climate and biology
- 4.) Drift material, soils, salts, ice, and atmosphere samples give information about Martian volatile history.

A new approach was suggested for rover and sample return missions as an alternative to the Mars Rover and Sample Return mission (MRSR). This approach involves "micro"-technology, that is, the use of several small rovers and sample return vehicles, individually launched on small, expendable launch vehicles (Delta or Atlas) rather than one or two large rovers and sample return vehicles on large (Titan IV) launchers. Risk management in the new approach involves making several tries using equipment of good reliability rather than making

a single try with a highly reliable item. Loss of the single piece therefore does not spell the end of a necessary and desirable mission. Cost is also reduced in the new approach, with a total cost goal between \$1.5 - 2B (VS \approx \$10B for MRSR). All earlier science objectives are met by the new approach. Returned samples would include 8-10 different sample types with a similar total mass to MRSR, but with relatively smaller samples from diverse areas.

OTHER MISSIONS

Other missions referenced during the course of the workshop include the Soviet Phobos mission (in which both spacecraft failed prematurely, but which reported substantial findings nonetheless) and the Mars-94/96 mission (which includes two spacecraft, and 2-3 small stations to cover the entire planet. It will also include balloons and a possible rover. Mars 94/96 will explore energetic particle environment above 300 km. Its orbital parameters are not firm at this time).

II.) SYSTEMS

Material in this section derives from output from the two working groups.

Systems were divided by the surface working group into landing, mobility, communications, habitat, power, and exploration systems. Landing, mobility, and habitat systems were further subdivided into systems for cargo (unmanned) and systems for humans (manned). Hence, landing systems were defined to include manned and unmanned landers. Mobility systems include manned and unmanned vehicles on the martian surface (rovers). Habitat systems include human habitats (living quarters, and work areas such as laboratories, shops, etc.), and storage facilities (for such items as supplies, fuel, and waste). Communications systems were defined to include ground to ground and ground to Mars orbital space systems. Power generation systems include generation (nuclear and solar), transmission (including subsurface power transmission lines), power conditioning, and storage (fixed and mobile) systems. Exploration systems include laboratories, greenhouses, materials and sample processing, etc. These definitions were used by the working group to gain hold of the types of operations and therefore environmental interactions to be expected on the martian surface.

Systems were defined by the orbital working group to include entry systems using aerobrakes, entry vehicles firing thrusters, or any other vehicles firing on-orbit thrusters, orbiting reconnaissance vehicles, surface to orbit ascent vehicles, and long term orbiting vehicles like a Mars space station.

III.) ENVIRONMENTS

Material in this section derives from output of the two working groups.

SUBSURFACE

The martian environment was subdivided by the surface working group into subsurface and surface realms. For the purposes of this meeting, the subsurface realm was taken to extend from the surface to a depth of $\approx 30m$. Of this subsurface realm, it was repeatedly pointed out that virtually nothing is known. Nor are any missions currently planned that will explore there. Yet, the subsurface is of obvious importance to the Exploration Program if permanent habitats and their supporting appliances (power generating stations with underground transmission lines, laboratories, materials processing plants, etc.) are to be placed on Mars. Structural foundations will certainly penetrate into the subsurface and will interact with the minerals, ices, fluids, and gases present there. Terrestrial structural mechanics must take subsurface characteristics into careful account in building design. The same is true for Mars.

The subsurface components of interest were identified as soil components, minerals, water, volatiles and/or trapped gases, and, with the placement of man made objects, system generated elements such as reactor heat and waste solids and fluids. Several questions were posed regarding these components:

- 1.) Is water present in the martian subsurface?
- 2.) Is it in solid or liquid form, fresh or brine?
- 3.) What is its global distribution? (This factor might be important to site selection).

Models exist which give some idea of how the water might be distributed as permafrost. These models need to be validated by in-situ measurements.

- 4.) Are volatiles and/or trapped gases present?
- 5.) What physical and chemical properties do they possess?
- 6.) What is the chemical reactivity of subsurface soil?
- 7.) What are its dielectric properties?
- 8.) What is the subsurface temperature profile; ie., how does temperature vary with depth on Mars?

SURFACE

The Martian surface environment was taken to extend from the visible surface of the planet to a height of approximately 1 km. It was considered by all to be a diverse and interactive system in and of itself, even without the introduction of man-made artifacts. Surface interactions were determined to be both spatially and temporally dependent due to the varied surface topology of the planet and the seasonal climate changes.

Surface components of interest were soil and dust, the duricrust layer, rocks and volcanically deposited materials, the atmosphere, its composition and moisture content, the solar spectrum, the spectrum of solar and cosmic radiation, volatiles, and system generated elements. Several questions were posed regarding these components:

- 1.) What is the composition and grain size distribution of martian dust as a function of location on the planet?
- 2.) How do variations in surface features, as volcanic terrain versus cratered terrain (etc.), affect local conditions and impact environmental interactions?
- 3.) What are the characteristics of the duricrust layer?
- 4.) How widely distributed is it and what effects ensue if it is disrupted as by the passage of a rover or heavy machine?
- 5.) In what electrical charge states are the dust grains?
- 6.) Do electrical forces play a significant role in soil agglomerate and dune formation?
- 7.) What mechanisms drive these charge states?
- 8.) What are the distributions and characteristics of dust and soil electrets?
- 9.) Are there dust and soil dipoles, magnetic or electric?
- 10.) What is the composition, temperature, and moisture content of the martian atmosphere?
- 11.) What is the magnitude and direction of the ambient electric field?
- 12.) What is the atmospheric dielectric breakdown strength?
- 13.) How do these parameters vary with location and time of year?
- 14.) How does this variation depend on insolation and on subsurface conditions?
- 15.) What is the dust content of the atmosphere and how does the presence or absence of atmospheric dust affect ambient light, electrical breakdown characteristics?
- 16.) What are the spectra of sunlight and of solar (flare) and cosmic radiation at the martian surface?
- 17.) What induced radiation levels may be expected, and how do they impact manned missions?
- 18.) What volatiles are present and where do they originate?
- 19.) What materials might be liberated by chemical and/or electrical processes?
- 20.) What materials might be liberated by mechanical processes?
- 21.) How will system generated components like reactor heat and waste materials affect local martian environments?
- 22.) Will disturbances to the duricrust add to the overall dust content of the atmosphere locally or on a planetary scale?

ORBIT

The Mars orbital regime (LMO) was defined by the orbit working group to extend from an altitude of approximately 100 km upward. As a planetary ionosphere with plasma and neutral species, this regime resembles low Earth orbit (LEO) to a first order of approximation. Specific parameters like particle number densities vary from terrestrial values, but at worst are still good to within an order of magnitude. A major difference between LMO and LEO is the absence of

an appreciable magnetic field in LMO. Several questions were posed regarding the components of the orbital regime: What is the specific nature of the ionosphere in terms of:

- 1.) Neutrals
- 2.) Plasma (electrons and ions)
- 3.) Atomic oxygen
- 4.) CO and CO₂
- 5.) The hot (≤ 60 KeV) O⁺ tail
- 6.) Dust from Phobos and Deimos
- 7.) Dust carried to high altitudes (≈ 100 km) by surface storms?
- 8.) Dust carried into orbit by ascent vehicles and other sources
- 9.) Radiation (optical and ionizing) and solar UV
- 10.) System generated elements such as propulsive effluents, and debris

Many of the questions posed above will be (or can be) answered by the missions described in a previous section of this report. Others cannot, particularly those involving the martian subsurface. The source of the questions about the environment is our current knowledge of Mars, based on results from Mariner and Viking. Thus, while it is known, for example, that CO₂, CO, and atomic oxygen are all present in Mars orbit, their specific abundances, their yearly variations, and so on, are not known but might be able to be determined by missions like MAO. Even with these uncertainties, however, it is still possible to identify a variety of environmental interactions in each of the three environmental realms. Knowledge of the specific characteristics of environmental interactions depends in all cases on detailed knowledge of the environments involved, and also on how specific interaction mechanisms (such as Paschen breakdown), once identified, operate in those environments. In many cases, Earth based laboratory experiments or application of already developed interactions models (as those developed for plasma interactions in LEO and GEO) will suffice to enable understanding to the degree of accuracy needed. In other cases, however, experimental packages must be sent to Mars to provide interactions data to guide ground based experiments and provide the basis for developing and validating new models.

IV.) INTERACTIONS

Material in this section derives from output of the two working groups. The interactions discussed are here sorted into electrical (including ionizing radiation), chemical, and mechanical interactions. The final section, "Knowledge Requirements - Recommendations," relates these categories back to the environmental regimes defined in the previous section.

ELECTRICAL INTERACTIONS

Electrical interactions include:

- 1.) Paschen breakdown of the martian atmosphere
- 2.) Breakdown of subsurface soil/atmosphere
- 3.) Electrical charging of personnel and machinery
- 4.) Electrical charging of dust (triboelectric and photoelectric)
- 5.) Dust interactions with systems
- 6.) Induced radiation levels at the surface
- 7.) Radiation effects in orbit
- 7.) Electrical interactions between orbiting space vehicles and ionospheric plasma
- 8.) Plasma generation accompanying aerobraking.

Paschen breakdown of the martian atmosphere: Paschen breakdown is a surface phenomenon which depends on atmospheric parameters such as pressure, density, composition, wind, and dust content. Paschen breakdown of the martian atmosphere begins at electrical potentials as low as a few hundred volts. The surface working group concluded that Paschen breakdown in the form of diffuse glows would be most probable at the surface. These glows are relatively easy to produce, and will almost certainly occur as coronas around exposed high voltage fixtures. They might even be seen around astronauts boots as they move over the surface and accumulate an electrostatic charge from the dry martian dust. By contrast, lightning-like discharges (filamentous rather than diffuse) are expected at kilometer scale heights, and might result from atmospheric disturbances such as intense dust storms. A Paschen discharge originating at km altitude and extending toward the ground would be seen as filamentous, gradually widening out to a diffuse glow as it approached the surface. Paschen discharge represents a power loss to electrical generating equipment, and to electronic instruments operating at voltages greater than a few hundred volts. It is also a source of electromagnetic noise which interferes with sensitive instruments and support system electronics (eg., mobile life support) operating on the surface. It is also a damage mechanism, particularly where the local electric field enables ionic bombardment of the surface.

Breakdown of subsurface soil/atmosphere: Power distribution on Mars will be accomplished by using transmission lines from the generator to the user just like on Earth. These transmission lines may be run on overhead towers, but structural components and heavy line insulation would then have to be transported to Mars. An alternative is to bury the transmission lines bare, making use of the insulating properties of martian soil and thus eliminating the need for transporting heavy structural elements and line insulation from Earth. In burying transmission lines, however, the breakdown characteristics of the subsurface atmosphere and the dielectric strength of the martian soil must be taken into account to prevent line to line breakdown and the resulting distributed power loss. Paschen-type breakdowns may be an important consideration in the subsurface realm.

Electrical charging of personnel and machinery: Personnel and machinery moving across the martian surface will accumulate electrostatic charge either by triboelectric means, or by direct transfer due to accumulation of dust dipoles and electrets. Stationary objects will also

accumulate electrostatic charge due to dust dipoles and electrets migrating onto and climbing up surfaces in response to Coulombic forces. The result of this charge accumulation is that differential electric potentials will develop between objects or individuals and the surrounding environment. These potentials make discharges between pairs of objects, or between an object and the ground extremely likely. The dry conditions at Mars are particularly conducive to electrostatic charging. Conventional grounding, which might otherwise serve to reduce the buildup of charge by ionic ground conduction, is not possible on Mars. Artificial ground planes might be established by burying conducting metal grids, but astronaut and vehicular mobility would then be limited in range whenever charging was an issue. The effects of electrical discharge through the martian atmosphere would be uncomfortable and could be lethal. One scenario considered the possible effect of an electrical discharge in a confined space with suspended dust, and concluded that an explosion hazard existed due to the chemical activity of the dust. In this scenario, the discharge became the "spark" that set off the explosive reaction. Destruction of the habitat was the result.

Electrical charging of dust; Dust interactions: Martian dust may become triboelectrically charged during dust storms, or during manned operations (such as construction) in which mechanical transport of dust and soil plays a role. Martian dust may also become photoelectrically charged. Electrically charged dust is able to move under the influences of wind and/or Coulombic forces and so migrate onto and accumulate on surfaces and in equipment (such as electrical power generating equipment), modifying lens and mirror optical characteristics, surface dielectric constants (coupling characteristics), thermal control surface (radiator) characteristics, and surface mechanical characteristics (abrasion). Severe dust accumulation is high voltage systems will produce direct shorting paths and power loss and/or damage due to electrical discharge. Dust is therefore an important consideration in all aspects of martian base operations.

Induced radiation levels at the surface; Radiation effects in orbit: The ionizing radiation environment at Mars primarily is due to two sources: the sun and the galaxy. The presence of radiation poses issues both for materials and system components, and for humans. High levels of ambient, steady state radiation degrade materials and expose humans to an increased risk of radiation induced illness. Transient events like solar flares produce additional, potentially lethal doses of radiation. The induced radiation environment at the Martian surface, and the orbital radiation environment must figure prominently into the design and establishment of a manned Martian base.

Electrical interactions between orbiting space vehicles and ionospheric plasma: In LMO, the orbital working group discussed electrical interactions between orbiting vehicles and ionospheric plasma. These interactions include spacecraft charging, spacecraft potential variations, structural current transients during charge/discharge events, and erosion due to local sputtering. Spacecraft develop electrical potentials in plasma in order to balance electron and ion currents from the plasma to the spacecraft body. An equilibrium condition exists when zero net current flows into or out of the spacecraft. Passage into and out of eclipse or into different regions of the ionosphere produces changes in spacecraft electrical potential and surface charge distribution. Under extreme conditions, arcs can occur. Arcs produce surface damage and can result in permanent changes to spacecraft electrical characteristics. All charge/discharge events,

however mild or extreme, produce electrical noise and can result in structural currents which disrupt spacecraft logic. Differential electrical potentials between vehicles results in potential shifts and discharge events during docking maneuvers. It was suggested by the orbit group that the LEO ionosphere provides a good first order model for understanding the LMO ionosphere, and that interactions models developed for LEO might be used directly or with some modification to guide LMO spacecraft design.

Plasma generation accompanying aerobraking: Plasma generation accompanying aerobraking was cited as a source of communications blackout, and a possible source of structural electrical currents. The ramifications of communication blackout are not clear at this time. The presence of structural currents raises the same type of concerns as cited in the previous paragraph.

CHEMICAL INTERACTIONS

Chemical interactions include corrosion of subsurface and surface structures, and erosion of orbiting structures.

Corrosion of subsurface and surface structures: The martian soil is known from Viking to be reactive. Martian dust contains silicates, carbonates, sulfur, superoxides, and iron. Gaseous oxygen and sulfuric acid are readily released from soil or dust with the addition of heat and/or water. Other reactive volatiles or trapped gases also may be generated and/or released from the martian subsurface. Waste reactor heat and disposed fluids, therefore, supply a necessary ingredient for all soil reactions, with the result that nearby structures may become susceptible to corrosion. Surface structures are also subject to the effects of atmospheric reactivity along with the other factors mentioned.

Example reaction scenarios suggested by the surface working group involved leaks or accidental spills in a storage area which enable reactions that degrade the integrity of other containment vessels in the area, thereby setting up potentially hazardous conditions. Such areas must be carefully monitored and controlled. The group also discussed corrosion of reactor containment walls beneath the martian surface where monitoring might be more difficult. Failure of such structures could lead to the unintentional release of undesirable chemical or radioactive species into the local martian environment.

Erosion of orbiting structures: The orbit working group focused on chemical and sputter erosion of orbiting structures by atomic oxygen, and by species derived from ambient CO and CO₂. Atomic oxygen is known to damage structures in LEO. In LMO, the atomic oxygen number density is similar to that in LEO and may be assumed to have similar effects. Sputtering and chemical erosion are also likely in the hot O⁺ ion tail. CO and CO₂ damage to refractory metals will occur when particle energies are enhanced in the spacecraft reference frame by the orbital velocity, or when high temperature operations such as nuclear propulsion or power generation are present. The orbital group also cited radiation and solar UV damage to materials, e.g., material darkening due to radiation or UV induced chemical breakdown within the material structure.

MECHANICAL INTERACTIONS

Dust impact was the predominant source of mechanical erosion cited by the surface working group. Dust may be transported by martian winds or by electrostatic forces as described earlier. Dust impacts on structural surfaces will cause abrasion of those surfaces. Lenses, mirrors, windows, radiators, and a variety of other structures are susceptible to the effects of dust erosion unless properly designed and protected. The presence and control of dust at a site were therefore considered important factors for a Mars base. Mobility systems, like rovers, will stir up considerable dust as they pass, and will break the duricrust which forms a thin, solid sheet over the Martian soil. The fine dust stirred by rover passage may remain suspended for a long time in the Martian atmosphere before settling. When Viking landed, the retro rockets injected dust into the atmosphere. This dust dissipated quickly (based on its effects in Viking imagery) but whether it settled or merely drifted away is not clear. Viking retro fire was a one time event. Continuous activity could seriously impact the amount of suspended dust with which astronauts will have to deal. Breaking of the duricrust (and re-breaking by repeated passage of astronauts or surface vehicles) will liberate loose material into the environment which may then be stirred and carried by the Martian winds.

The orbital group cited abrasion of spacecraft surfaces by orbital dust as from the martian moons, and damage to S/C surfaces by meteoroid and debris impacts including denting, pitting and penetration. The group also raised the question of how atmospheric dust loading will impact aerobraking.

V.) KNOWLEDGE REQUIREMENTS - RECOMMENDATIONS

SUBSURFACE & SURFACE

The surface working group defined Martian surface systems interactions by first considering the intrinsic Martian weather system as an interactive whole. It argued that environmental components like dust, wind, temperature, insolation, and surface radiation are interrelated in a complex way which forms a network of nodes and feedback loops into which surface systems are introduced as additional nodes with additional loops. The interchange of information throughout this complex system comprises a set of surface environmental interactions (including system dependent and system independent interactions) which must be identified and understood.

It was concluded by the surface working group that: *No hard knowledge exists of the Martian subsurface, and that, while structures in Martian bases must interact with the subsurface, no missions are currently being planned to explore into this realm.* Typical questions with which systems designers must deal involve feasibility of burying electrical transmission lines, using insulating properties of the soil, to save on insulator and support tower mass, and feasibility of placing nuclear reactors in surface depressions thereby using Martian soil as shielding. Given the fact of soil reactivity, these buried materials will be susceptible to corrosion in the presence of water and/or reactor generated heat. Transmission lines may also

be subject to electrical breakdown through the subsurface medium. To address these issues, the following information is required:

- 1.) *The presence or lack of subsurface water and its state (liquid or solid, fresh or brine)*
- 2.) *Subsurface soil mechanics and mineralogy*
- 3.) *Mechanical, thermal, electrical, and chemical properties of subsurface rocks and soil*
- 4.) *The nature and distribution of volatiles and their chemical properties.*

Therefore, surface rovers should include instrumented probes to characterize the subsurface whenever and wherever such inclusion is feasible.

On the martian surface, dust plays a major role in just about all of the surface interactions considered. Suspended dust, or dust moving under the influence of electrical forces, will migrate onto, accumulate, and so contaminate electrical power generating systems, and optical and thermal control surfaces. Electrical charge transfer may also occur due to charging of individual dust grains. Because of its extreme reactivity, suspended dust inside habitat modules creates an explosion hazard unless carefully controlled by precipitators or humidity. Dust reactivity also poses a corrosion hazard wherever moisture is present. To address these issues, the following information is required:

- 1.) *Surface soil mechanics and mineralogy*
- 2.) *Mechanical, thermal, electrical, and chemical properties of surface rocks and soil*
- 3.) *The explosion potential of suspended dust in confined volumes*
- 4.) *The nature and distribution of volatiles and their chemical properties.*

Since these characteristics vary from locale to locale across the Martian surface, global determinations and mappings may be necessary. *Therefore, robotic missions (whether surface rovers/landers for in situ observations or orbital for remote global reconnaissance) are recommended to characterize the surface.*

The Martian atmosphere also is reactive, and capable of sustaining Paschen type electrical breakdowns. Glows are to be expected near the Martian surface, and lightning-like discharges at altitudes of the order of a kilometer or more. Discharges near high voltage surfaces will result in electrical power loss in generating systems, and may serve as an ignition source to dust explosions in contained spaces. Dust carried about during Martian dust storms will likely charge and create locally strong electrical fields which could produce atmospheric breakdown. At a minimum, such breakdowns are a source of EM noise to instruments operating on the Martian surface. To address these issues, the following information is required:

- 1.) *The thermal and electrical breakdown characteristics of the Martian atmosphere in the presence and absence of dust, with and without wind, and the magnitude and direction of the ambient electric field.*

The surface radiation environment will impact all aspects of a Mars mission, human and

systems related. While an adequate knowledge base exists to deal with radiation environments near the Earth and in interplanetary space, knowledge of Mars specific environments is lacking. Analysis of induced radiation using isotopic concentrations of Martian soil may be all that is required to evaluate the potential interaction hazard. To address this issue, the following information is required:

- 1.) *Solar flare and galactic cosmic ray radiation spectra*
- 2.) *Models to estimate levels of induced radiation*
- 3.) *Surface mapping of induced radiation levels.*

Therefore, surface robotic missions must include appropriate instrument and experimental packages to achieve these objectives whenever it is feasible for them to do so.

While the planned Mars Observer, MESUR, MAO, and Mars 94/96 missions will provide much needed data on conditions at the planet, it was agreed that additional information must be sought on:

- 1.) Surface conditions such as composition and distribution of native materials
- 2.) Dust processes associated with disruption and reformation of the duricrust
- 3.) Chemical activity, nature and distribution of volatiles
- 4.) Chemical composition and breakdown characteristics of the atmosphere in its various states of rest and motion, dustiness and relative clarity
- 5.) Reactivity of soil and atmosphere in the presence of heat and fluids
- 6.) Solar and galactic cosmic ray radiation spectra and induced surface radiation levels
- 7.) Abrasive properties, electrical properties (including electret and dipole formation), and melting/decomposition properties of dust
- 8.) Explosion characteristics of Martian dust suspended in closed volumes.

Many details are lacking and can only be filled by in-situ measurements on the Martian surface. *It was suggested that existing or planned missions (cited above) be used to accomplish as many of the suggested objectives as possible. In some cases, these missions may need to be extended or modified to include additional experiments. In other cases, entirely new missions will be required to obtain the necessary information. Some laboratory based work is possible in facilities like the Mars wind tunnel at NASA/Ames and similar facilities elsewhere. A simulant for Martian atmospheric gas is already available. A simulant for Mars dust is not, but would be of enormous value. This dust simulant might be derived from careful studies of existing Mars data, even without further robotic missions to the planet.*

ORBIT

The orbital working group defined issues in the spatial regime extending from 100 km altitude upwards. These issues include:

- 1.) Atomic oxygen erosion of materials

- 2.) CO₂ damage to refractory metals
- 3.) CO chemical reactions
- 4.) Plasma interactions in the ionosphere
- 5.) Erosion and charging due to a hot O⁺ tail (≤ 60 KeV) extending behind the planet
- 6.) Dust erosion
- 7.) Penetration by particulates like meteoroids and ejecta from the moons
- 8.) Man-made debris including particulates from propellants
- 9.) Radiation (optical and ionizing) and solar UV damage to materials
- 10.) Aerocapture related effects including those due to locally generated plasma and dust erosion, and effects of such atmospheric anomalies as gravity waves
- 11.) Transport of surface dust into orbit by ascent vehicles
- 12.) System generated environments and their effects

These twelve issues break into four broad groups: i.) electrical interactions with plasmas and neutrals which include spacecraft charging, spacecraft potential variations, structural currents, and erosion due to local sputtering; ii.) interactions with particulates (solid materials like meteoroids and debris) in low Mars orbit (LMO) which include mechanical erosion or penetration of spacecraft surfaces; iii.) chemical interactions which include erosion by atomic oxygen and/or species liberated from local CO and CO₂, and photochemical reactions on surfaces and degradation within materials due to the presence of solar UV; and iv.) radiation interactions including the effects of cosmic ray and solar flare particles on humans and on system components.

In Mars orbit, it was concluded that *ionospheric plasma and atomic oxygen interactions models developed for near Earth space provide a first order approximation for LMO, but that additional work is still needed to define the Mars orbital environment and provide necessary background for understanding specific interactions there.* (A model of the Martian atmosphere for use in orbital lifetime studies is provided by Stewart (1987; see bibliography)). Thus, we may say that charge/discharge phenomena will certainly occur with possibly disruptive transients, but specific discharge characteristics under specific sets of conditions may not be able to be specified without more detailed information about the Martian orbital environment itself. Similar arguments may be formed for the other areas cited as well. Specifically, little is known about the hot O⁺ tail or the interactions mechanisms which are involved with it.

Included in the group's recommendations were robotic precursor missions to:

- 1.) *Comprehensively map the atmosphere in LMO, including the spatial and temporal characteristics which affect orbital mechanics, and ascent/descent maneuvers (including g-wave characteristics and drag uncertainties), diurnal and solar cycle variations in the temperatures and densities of atomic oxygen, the hot O⁺ tail, CO, and CO₂ populations*
- 2.) *Determine the effects of high energy impacts with all of these species upon spacecraft structures and materials*
- 3.) *Evaluate and define the Mars specific radiation environment including solar wind, solar flare, and galactic cosmic ray components*
- 4.) *Measure suspended dust populations and size distributions over time*

- 5.) *Understand impact cloud characteristics corresponding to aerocapture altitudes, velocities and densities*
- 6.) *Evaluate system generated effects such as those due to the addition of effluents or solid debris.*

It was proposed that several of these test and measurement functions might be combined in one spacecraft or platform like the Aeronomy Observer with time varying orbital parameters and sufficiently diverse instrumentation. *Additionally, it was recommended that ground tests and model development either be continued or begun. Specific areas of opportunity include:*

- 1.) *Subsystem laboratory tests and analytic modeling of spacecraft plasma interactions in a martian cold plasma environment*
- 2.) *Laboratory measurements of sputtering and erosion interactions at 60 KeV energies.*

These activities must keep pace with SEI program development and ensure timely availability of design tools for SEI system engineers.

WORKSHOP AGENDA

19 NOVEMBER 1991:

8:30 AM TO 12:00 NOON:	TALKS AND DISCUSSION
12:00 NOON TO 1:00 PM:	LUNCH
1:00 PM TO 5:00 PM:	TALKS CONTD. / WORKING GROUPS

20 NOVEMBER 1991:

8:30 AM TO 12:00 NOON:	WORKING GROUPS
12:00 NOON TO 1:00 PM:	LUNCH
1:00 PM TO 2:30 PM:	WORKING GROUPS CONTD.
2:45 TO 4:00 PM:	CHAIRMEN PRESENT RESULTS

WORKSHOP OBJECTIVE

- I.) Subject: Electrical and Chemical Systems-Environmental Interactions at Mars.
- II.) Context: Systems for the Exploration Initiative; Environmental Interactions on the Surface and in Orbit.
- III.) Objective: Review what we already know, ascertain what we need to know, find the holes, and recommend ways to fill them via models, laboratory experiments, or robotic precursor missions.

WORKSHOP ATTENDEES

WORKSHOP CHAIRMEN:

Joseph C. Kolecki, NASA Lewis Research Center
G. Barry Hillard, NASA Lewis Research Center

PARTICIPANTS:

Larry Brace, University of Michigan
Tammy Dickinson, NASA Headquarters, Code SL
Dale Ferguson, NASA Lewis Research Center
Robert Haberle, NASA Ames Research Center
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Tim Van Sant, NASA Goddard Space Flight Center
Alan Willoughby, NASA Lewis Research Center

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<p>The Electrical and Chemical Interactions at Mars Workshop, hosted by NASA Lewis Research Center on November 19 and 20, 1991, was held with the following objectives in mind: (1) to identify issues related to electrical and chemical interactions between systems and their local environments at Mars, and (2) to recommend means of addressing those issues, including the dispatch of robotic spacecraft to Mars to acquire necessary information. The workshop began with presentations about Mars' surface and orbital environments, Space Exploration Initiative (SEI) systems, environmental interactions, modeling and analysis, and plans for exploration. Participants were then divided into two working groups: one to examine the surface of Mars; and the other, the orbit of Mars. The working groups were to identify issues relating to environmental interactions; to state for each issue what is known and what new knowledge is needed; and to recommend ways to fulfill the need. Issues were prioritized within each working group using the relative severity of effects as a criterion. This report describes the two working groups' contributions. When materials were available in viewgraph form, the presentations given at the outset of the workshop are included as an appendix in Part II, published as a separate document. A bibliography of materials used during the workshop and suggested reference materials is included.</p>			
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